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PARAMETERS OF THE WWR-M REACTOR OF THE PHYSICS INSTITUTE OF THE UKRAINIAN ACADEMY OF SCIENCES AND ITS APPLICATION FOR THE NUCLEAR PHYSICS RESEARCH.

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I. Neutron Fluxes.

The IO MW WWR-M research reactor of the Physics Institute of the Ukrainian Academy of Sciences /I/ has 9 radial horizontal channels, a thermal column and I3 vertical channels (Fig.Ia, Ib). At the nominal power level the average thermal neutron flux in the core is about $IO^{I4}n/cm^2$ sec. A number of works were carried out since the starting up of the reactor (II.I960). Some of them were devoted to the reactor parameters studies and others to the development of its assemblies and units.

The reactor neutron and γ -ray spectra were pub-

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lished earlier /3,4,5/.

For measurements of the relative distributions of thermal neutron fluxes in the reactor core and channels a copper indicator activation method was used. The measurement of the absolute value of the thermal neutron flux was made by the gold foils activation and measuring of their absolute activity by a β-γ coincidence technique /6/.

So far as the experimental fast neutron spectrum of the reactor is known the absolute value of the fast neutron flux is easily obtained from the absolute activity of the threshold indicators.

In Fig. 2,3,4 the thermal and fast neutron flux distributions in the reactor channels are given for the core configuration, represented in Fig.5.

At the reactor power level IOMW the neutron fluxes are: in the centre of the core IO^{I4n}/cm^2.sec., in the centre of the water cavity $3.2.IO^{I4n}/cm^2$.sec., at the horizontal channel outlet $3.7.IO^{9n}/cm^2$.sec.

2. The Increase of the WWR-M Reactor Power Level.

These studies were carried on the two directions: I)the investigation of the fuel element temperature conditions in the core; 2) the development of sensitive methods of the fuel element leak control.

The thermal measurements were made to obtain:

a) the temperature distribution of fuel element surface along the haight and core radius;

b) the effect of the control and safety rods upon this Distribution;

c) the optimal choise of coolant flow rate for a given power level.

For these measurements a single fuel element was equipped by chromel-alumel thermocouples, situated on its surface, the diameter of the thermocouple wire being O.05 - O.I mm.

In the first run the influence of the Be reflector

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and control and safety rods on the surface temperature of the element located near the water cavity was studied. It appeared that the surface temperatures at the cavity side and at the core side do not appreciably differ. The closeness of control rods influences the surface temperature considerably. Curves I and 2 (Fig.6) show the surface temperature at the control rod side for cocked (curve I) and inserted (curve 2) positions, and curves 3 and 4 show the same at the opposite side of the element for similar positions. In Fig.7 the radial core temperature distribution is represented. It is seen that the most thermally stressed core region is at its periphery near the Be reflector. For this region at a fixed flow rates of coolant the power level providing the temperature at the surface of full element equal to 94-95^{o}C has been achieved. Fig.8 gives the temperature along the element height at I2 MW and flow rate I300 m^3/h.

The above results can be summarized in the nomogram (Fig.9) that shows the ultimate power levels at the definite cooling conditions of the core. Along with this the element surface temperature (right-hand plot) and the cooling water temperature (left-hand plot) at the arbitrary power and flow rate are given.

At the reactor maintenance much attention was paid to the radiation security and elimination of environmental hazards. For this purpose a radiation area survey service was organized which systematically checks the natural γ - background of the fall-out, the activity of soil, vegetation and water both near the reactor and far from it. Any change in the reactor work conditions is always accompanied by the outer radiation control. Moreover, an effective leak control method for the fuel elements in the core was developed and regularly applied.

The element leak control was accomplished by a small ionization chamber into which the gaseous products of fission and radium emanation were pumped over from the large vacuum-chamber. The chamber volume ratio is I:I00. The diagram of the device is shown in Fig.IO.

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The scheme of the leak checking device is shown in Fig.10. For checking a fuel element is placed into the vacuum chamber, washed there, and then the chamber is vacuumed for half an hour. The gaseous products of fission and radium emanation which leak out of a demaged fuel element are supplented by distilled water from the vacuum chamber into ionization chamber the volume of the latter being one hundredth of the vacuum one.

When there is a leak the chamber gives a current, recorded on a chart.

3. The Nuclear Investigations.

The high neutron flux in the core, the possibility to vary the core configuration and the convenient reactor design allow for a wide range of experimental studies in different regimns of science and engineering.

The investigations are made in nuclear physics, physics of condensed media, radiation material studies, chemistry and biology, according to the interests of the Academy of Sciences and other institutions of the Ukrainian SSR. The works on the last three subjects are published elsewhere /7,8/ and are not considered in this report. Here we consider only a few examples of nuclear investigations.

First of all we want to dwell upon the neutron spectrometry using the time-of-flight method. By this method the total and partial cross sections of the slow neutron interaction with nuclei are being measured. High flux reactor is particularly valuable for measurements of neutron cross sections of separated isotopes, available in small quantities. The measurements are made on the channel No.2, where the neutron beam is extracted directly from the core (Fig.16). This, in addition to the conical collimator system giving a convergent neutron beam, provides a maximum neutron flux in the resonance region. This channel is equipped by a single-slit neutron chopper with the 0.25 by 25 mm Slit.

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The resolution of the chopper is $0.2\frac{\mu sec}{m}$ /9/. Fig.I8 shows the thermal neutron spectrum, measured at I2 MW with the Re I85 sample in the beam (slit 0.25 by I4 mm).

The analysis of data obtained shows the possibility of measurements the neutron cross sections with beams of 0.5 mm^2 or less by means of this technique.

Fig. I9 represents the results of the total neutron cross section measurements on separated isotopes of Er^{I66}, Er^{I67}, Er^{I70} in the thermal region with resolution $3\frac{\mu sec}{m}$. Fig. 20 shows similar cross sections in resonance region with resolution $0.4\frac{\mu sec}{m}$.

The comparison of results obtained enables one to make an isotopic indentification of levels and to determine their resonance parameters (Table I). The cross section of natural erbium at $2200\frac{m}{sec}$ is determined mainly by the Er^{I67} isotope because of its two levels at 0.46 ev and 0.58 ev. As could be expected, the cross sections of even A erbium isotopes are much lower than that of Er^{I67}. The magnitude of the total cross sections in the thermal region can hardly be explained with a help of the positive levels obtained early. It is possible that the large cross sections arise due to the negative levels, but, as no careful analysis was done the question is still open.

The investigations of total and partial neutron cross sections are also carried on at the channel No.9, where a I75-meter vacuum pipeline for neutron time-of-flight researches with three stations for detectors was fuilt. The measurements can be made within the first 25 meters practically at any distance and also at distances 70, I25 and I75 meters. A set of mechanical choppers of different transmissions and resolutions is provided, allowing for measurements with resolution up to $0.0I\ \frac{sec}{m}$ / 9,I0 /.

In Fig.2I the cross section of natural rhenium measured with $0.05\frac{sec}{m}$ resolution is represented. The isotope level indentification was done from the single-

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slit chopper measurements. At preset another mechanical chopper with diameter 500 mm is being istalled at this channel /II/, having six divergent slits from 0.25 to 6 mm. This chopper will allow aslo to measure the total cross sections of separated isotopes available in small quantities with 0.02 $\frac{\mu \text{ sec}}{\text{m}}$ resolution. The flight time measurements are made by means of I024-Channel time analyzers with ferrite memory / I2 /.

In the first beam studies of differential cross sections of slow neutron inelastic scattering by the moderators on the thermal and epithermal regions are made by specialists of the Kurtchatov's Atomic Energy Institute. The monochromatic neutrons (resolution 0.2) are singled out by a mechanical monochromator with parabolic slits /Fig.22/. The scattered neutron spectra can be measured at anqles 15°,30°,60°,90° and 120°. To increase the beam intensity the beam is extracted from the neutron flash-up in the berillium reflector. Moreover, to increase the neutron flux a water trap in the core near this channel was made. Fig.23 gives the spectrum of scattered neutrons at 90°.

The differential cross seccions of slow monochromatic neutrons with energies I6;46.6; 50.7; I02.3; 200 and 326 meV inelastically scattered on water and monoisopropyldiphenyl ($C_{I5}H_{I6}$). From the cross sections obtained the average scattering characteristics $E'(E)$, $\gamma(E)$ $\overline{\cos(\theta)}$, M_2 and others were calculated. The comparaison of cross sections and average characteristics of neutron scattering on water and monoisopropyldiphenyl shows that the chemical binding of hydrogen in monoisopropyldiphenyl is stronger than in water and the thermalization process of neutrons in monoisopropyldiphenyl is slower than in water.

The scattering law $S(\alpha, \beta)$ and draw the generalized spectrum $P(\beta)$ for H_2O at T-23°C have been determined the data obtained can be used for neutron spectra calculations in the systems with water and organic moderators. More detailed description of the experiment and results is given in / I3 /.

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The research programm in the cold neutron region involves the investigations of total neutron cross sections is energy and the dynamical structure of condensed phases studies with the help of inelastic scattering.

Fig.25 shows the results of the measurements of total neutron cross sections of liquid oxygen and nitrogen in the 4-I2 Å range, obtained by means of the neutron monochromator. One may notice a decrease of the cross section at 5,5 Å. This effect is similar to the cross section fall in crystals and can be attributed to the existance of the close order in liquids.

For studies in the cold neutron region a berillium filter cooled by the liquid nitrogen was designed. Also a simple mechanical slow neutron monochromator with longitudinal rotation axis and a simplified mechanical neutron chopper were built. The mechanical monochromator consists of two discs of 580 mm dia and 60 mm thick, spaced by 600 mm. The discs have 48 radial slits 2.7 mm wide and 80 mm height. As the collimator 40 mm wide has I7 slits, in any moment one of the slits is necessarily open. The monochromatisation is accomplished by the incline of the shaft with respect to the neutron beam within 5^{o}.

This effect especially manifests itself when the coherent diffraction prevails. It should be noted that the coherent diffraction cross sections are for oxygen 4.2 and for nitrogen II barns.

The increase of the cross section of the gases against the decrease of energy is supposed to be conected with unelastic scattering on rotational levels of nitrogen and oxygen molecules.

In liquid a cross section for unelastic interaction shows a deep fall. From this follows that in liquid the rotational movements are prohibited to great extent. Such investigations including temperature dependens will be of undoubtful interest for gaseous condensation mechanism studing.

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Table I

Levels and Neutron Cross-Sections of Erbium Isotopes.

Isotope	Energy of levels (ev)	σ (barns)	$g\Gamma_{n\sigma v}$	Total cross section at the velocity 2200 m/sec in barns
I66	I5,9± 7 x)	$(5\pm0,5).10^3$	0,003±0,00I	84±I0
I67	0,46±0,0I2	-	-	6I0±I6
	0,584±0,02	-	-	
	6,00±0,I7	$(74\pm8).10^3$	0,0I5±0,004	
	9,35±0,34	$(I7\pm3).10^3$	0,005±0,00I	
	20,4±I,I 27,I±I,7 xx)	$(33\pm7).10^3$	0,075±0,0I0	
I68	+	-	-	37±5
I70	98±II			45±6

x) In BNL-325 are given two levels in the region of I5 ev: I5,4 and I5,7 ev. If it is so, than we can state, that level I5,4 ev belongs to Er^{I66}, because for natural erbium I5,4 ev level neutron width much more neutron width of the I5,7 ev level.

xx) The situation in this region is the same, as for I5 ev - case. Sowe can state, that 25,9 ev level, which is reported in BNL-235, belongs to Er-I67.

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The List of Figures of the Report
"Parameters of the WWR-M Reactor of Physics Institute of the Ukrainian Academy of Sciences and its Application for the Nuclear Physics Research"

Fig.I. a) Horizontal cross section of the reactor:
I. Control system channels
2. Technological section
3. Horizontal channel for experiments with neutron beams
4. Be-reflector
5. Thermal column.
b) Vertical cross section of the reactor:
I. Water entrance
2. Water excite
3. Horizontal channel for experiments with neutron beams.
4. The reactor vessel
5. Thermal column.

Fig.2. Radial (the neutron beam hole No.2) and height (chankels 42/60 and 62/60) neutron flux distribution in the reactor.

Fig.3. Absolute values of the thermal and fast ($E_n \geq$ I M ev) neutrons in the channels 75/60; 63/60; 62/60; 7/60; 95/60.

Fig.4. Absolute values of the thermal and fast neutrons in the channels 36/60; 42/60; 46/60:

Fig.5. The configuration of the core of the reactor.

Fig.6. The Influence of the control rod on the temperature of the fuel rod wall.

Fig.7. Fuel rods temperature distribution vs the core radius.

Fig.8. Fuel rod temperature distribution vs the core height.

Fig.9. The conditions of the reactor cooling at different power levels.

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Fig.IO. A Scheme of the system:
I - evacuated chamber, 2 - ionization chamber, 3 - filter, 4 - for vacuum ballon, 5 - for vacuum pump, 6 - water level indicator, 7 - vessel for distillated water, 8 - self-recorder of ionization current, 9 - self-recorder of fuel-rod temperature.

Fig.II. Scheme of the Experiment on the neutron cross section of separated isotopes:
I. The reactor core
2, The reactor schield
3. Collimators
4. The neutron chopper
5,6. Boron-hydrogen shield at the chopper excite
7. Chopper Shield
8. Vacuum evacuated tube
9. Detector station shield
IO. $B^{IO}F_3$ - detector
II. Boron shield of the detector
I2. Neutron trap.

Fig.I2. Experimental thermal neutron spectrum with the sample Re^{I85}(area of the neutron beam 0,25 x IO mm^2) on γ -axis-intensity in thousand counts per channel per hour, on X -axis-time of flight. One channel - $3,4\frac{\mu sec}{m}$. Power level of the reactor - I2 Mwt. n - $3,39.IO^{2I}\frac{nuclei}{sm^2}$.

Fig.I3. The total thermal neutron cross sections of the isotopes of Erbium (resolution $3,4\frac{\mu sec}{m}$).

Fig.I4. The total resonance neutro n cross section of the Erbium isotopes (resolution $0,4\frac{\mu sec}{m}$).

Fig.I5. Natural rhenium transmission vs neutron time of flight. Levels indentification has been made by means one-slit chopper.
Energy levels 2,I56;5,93; 7,I8; II,94; I2, 90; I4,74; 2I,46; 34,08(?) and 4I,50 ev are ones of Re-I85.
Energy levels 4,4I; II,20; I6,I6;I7,69; I8,53; 32,57(?) and 39,60 ev are ones of Re-I87.

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The Sample Thickness 4,537 gr /cm^2.

Fig.I6. The Experiment on measurements of angular distributions of the inelastic scaltered neutrons in slowing-down media.

Fig.I7. A - Spectrum of scattered neutron by H_2O at 90°; incident neutron energy III,5.I0^{-3}ev.

Fig.I8. Total neutron scattering cross section of liquid nitrogen at the 77°K vs neutron wave length. Upper curve - total scattering cross section of N_2-gas (given for comparison). Measurements with liquid nitrogen has been made with the chopper and the monochromator.

Fig.I9. Total cross section of liquid oxygen at boiling temperature vs neutron wave length. Upper curve-data for gas (BNL-325).

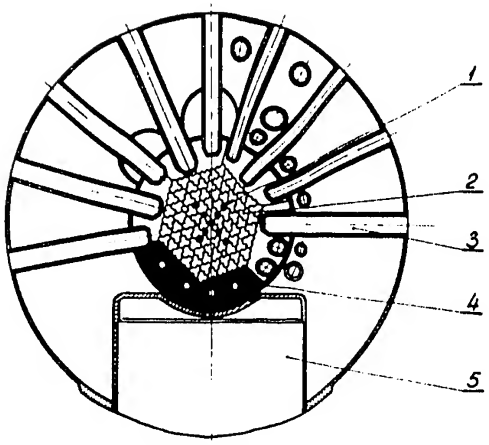

Fig. 1a

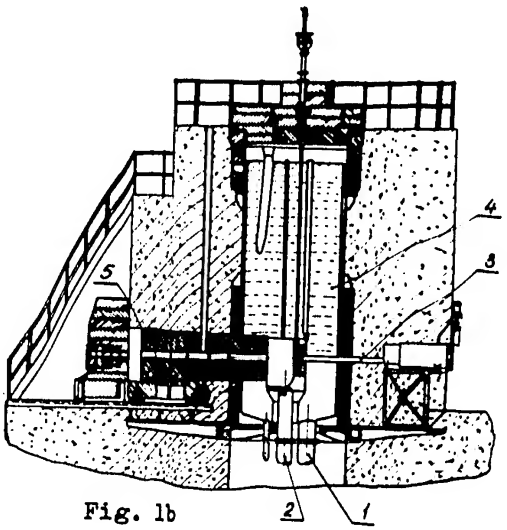

Fig. 1b

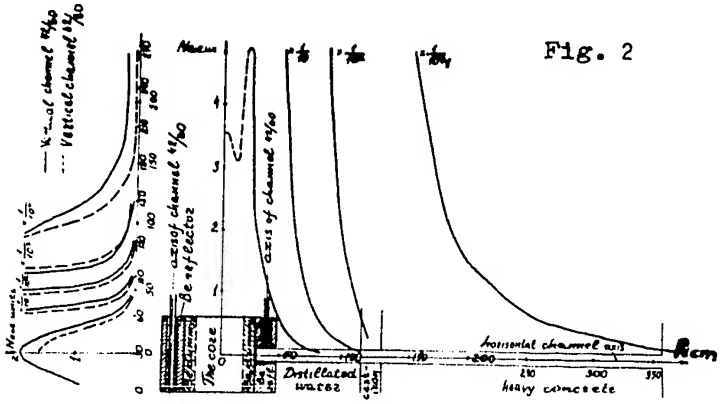

Fig. 2

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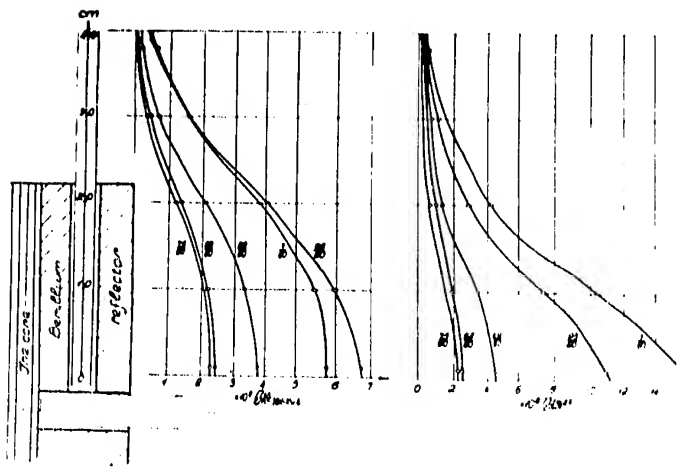

Fig. 3

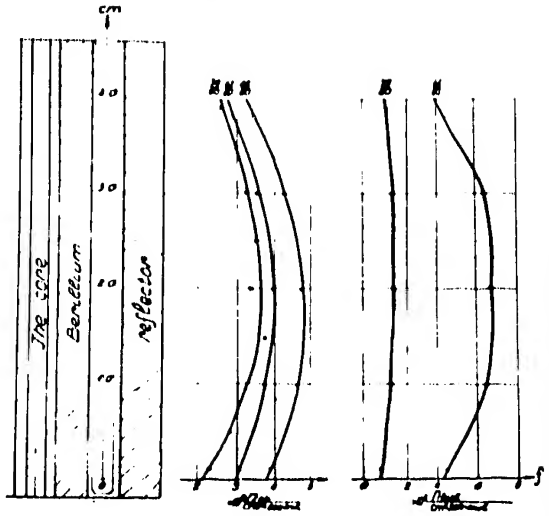

Fig. 4

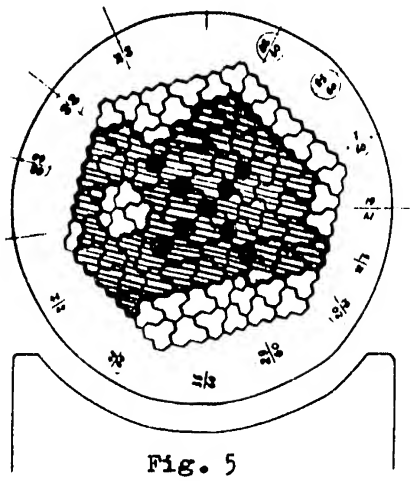

Fig. 5

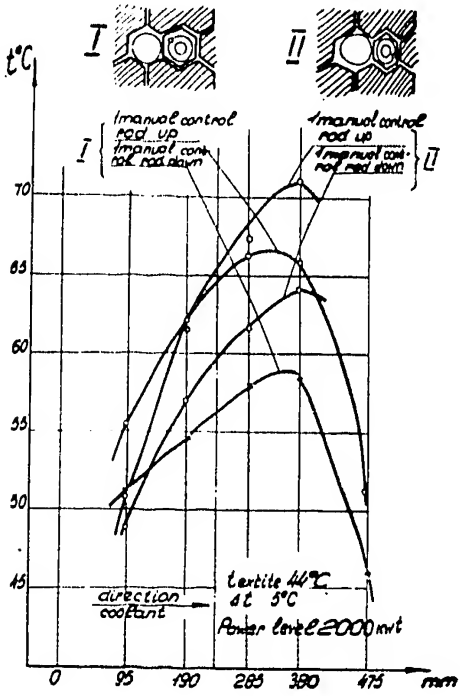

Fig. 6

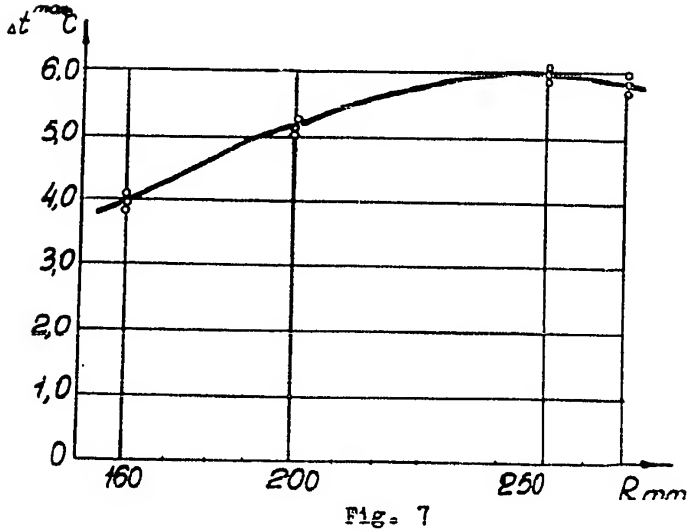

Fig. 7

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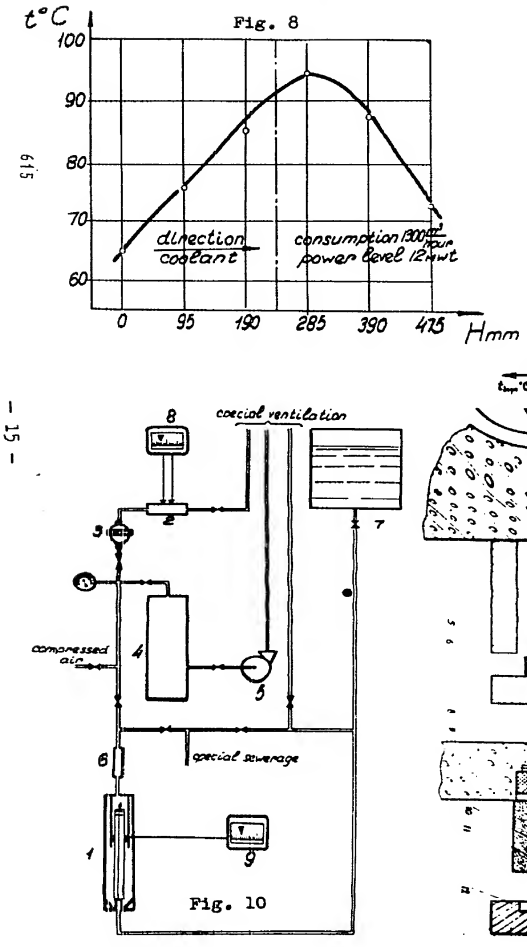

Fig. 8

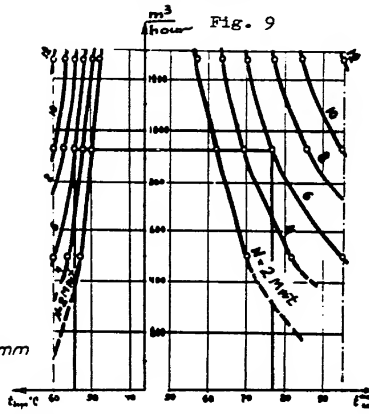

Fig. 9

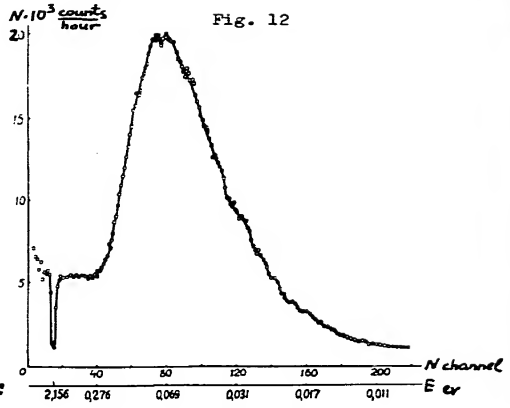

Fig. 12

Fig. 10

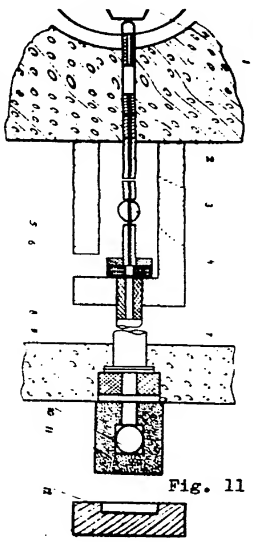

Fig. 11

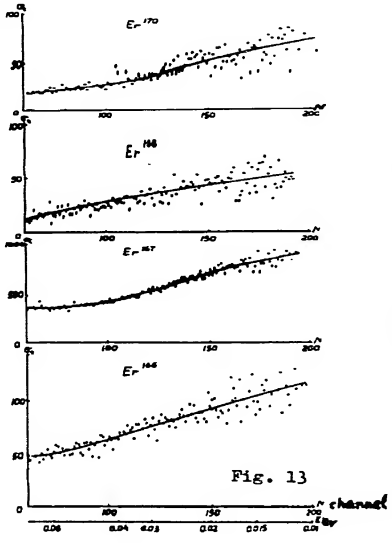

Fig. 13

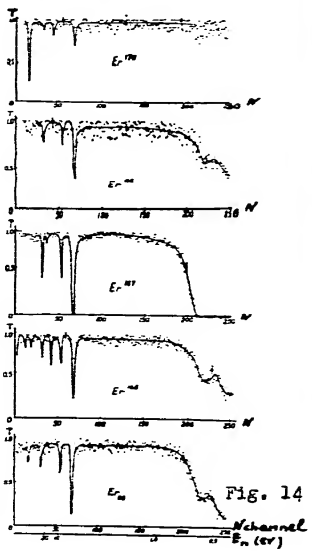

Fig. 14

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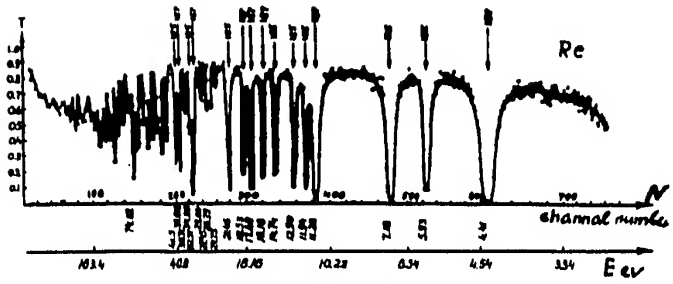


Fig. 15

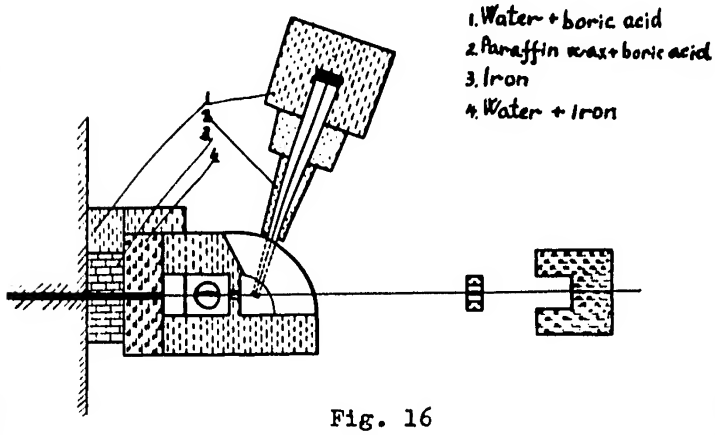


Fig. 16

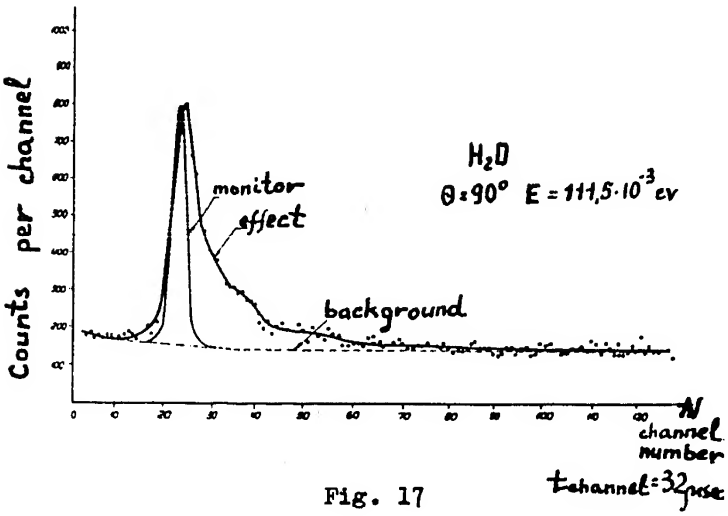
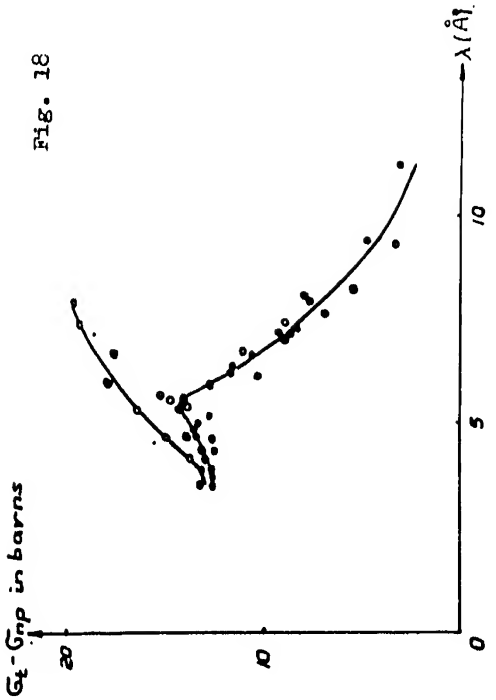


Fig. 17

Fig. 18



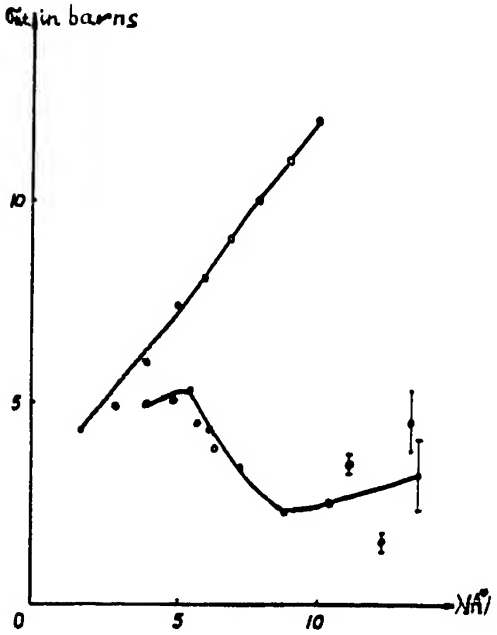


Fig. 19

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